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ANALYTIC STUDY OF EXTRACTION FORCES
IN THE M16 WEAPON

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Frankford Arsenal
Philadelphia, Pennsylvania

October 1973

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A theoretical model for predicting cartridge case extraction forces in a conventional small arms weapon is established. A parametric study involving six geometric and materials parameters for both conventional brass and 7475 (TMT) aluminum 5.56 mm cases in the M16 weapon is presented. Results defining the lowering of extraction force in terms of six materials and design factors are stated. It is found, based on these results, that the aluminum case is superior to brass in ease of extraction.		

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GLOSSARY

- A - Area of contact between a segment and chamber, Equation 6
- A* - Area over which unbalanced pressure acts, Equation 6
- E - Young's Modulus, Equation 2
- F - Force of extraction, Equation 6
- P - Propellant pressure, Equation 1
- P* - Residual case pressure, Equation 6
- r - Radial coordinate, Equation 1
- t - Shell thickness, Equation 1
- u - Radial displacement, Equation 4
- w - Axial displacement, Equation 4
- Z - Axial coordinate, Equation 1
- α - Shell half apex angle, Equation 1
- β - Constant, Equation 3
- $\Delta\epsilon_p$ - Super increment of equivalent plastic strain, Equation 2
- σ_e - Equivalent plastic stress, Equation 2
- ϵ_p - Equivalent plastic strain, Equation 2
- ϵ_r - Total radial strain, Equation 2
- ϵ_z - Total axial circumferential strain, Equation 2
- ϵ_θ - Total circumferential strain, Equation 2
- θ - Circumferential coordinate, Equation 1
- μ - Coefficient of dynamic friction
- ν - Poisson's ratio, Equation 2

GLOSSARY - Con't

σ_y - Yield stress, Equation 3

σ_r - Radial stress, Equation 1

σ_z - Axial stress, Equation 1

σ_θ - Circumferential (hoop) stress, Equation 1

INTRODUCTION

The objectives of the Small Arms Project 1J662604A607, Component, Exploratory Development, AR, are to provide exploratory development of new or improved munitions components and ammunition simulation. Task 25 of this project, Simulation - Ammo Math Modeling, deals with the mathematical modeling of ammunition, and part of the work performed under that task is presented in this report.

This study was initiated to develop an improved analytical extraction force model, capable of simulating experimental extraction data, and accounting for the dynamic effects which occur during weapon functioning. Such a model has been developed and is reported here. Extraction forces for 5.56 mm brass and aluminum cartridge cases for a broad range of materials parameters and several levels of functioning in the M16 are given.

Two factors are critical in the design of cartridge cases for conventional small caliber weapon systems. The first is the ability of the case material to maintain sufficient structural integrity to function, extract and be ejected. The second factor involves selecting case materials of: minimum weight, high strength, high availability, and low cost. It is part of the first factor, extraction, which is considered here for the M16 weapon.

The sequence of extraction and ejection of a spent case subjects that case to a number of forces and moments. These forces and moments are caused principally by: the motion of the bolt group, the inertia of the case, the extractor-ejector mechanism, the motion of the firing pin, the rearward propellant gas thrust, and the friction between chamber and the case during extraction. The present effort concentrates on these two latter forces: friction and gas thrust; other forces are ignored. Ejection is treated elsewhere.¹

Previous analytic methods for calculating extraction forces have used various simplified models. Read, et. al.² considered the cartridge case to be a very long metallic cylinder. This cylinder deforms radially due to propellant gas burning; expands and subsequently contracts together with the chamber. The elastic and strain-hardening characteristics of the metal were neglected; thus the case was rigid - perfectly plastic.

¹C. Synder, Private Communication.

²T. A. Read, et. al., "The Calculation of Yield Strengths in Steel Cases," FA-LC R-138, pp 1-27, Feb 1942.

Technik, Inc.³ improved the model of Reference 2 by including provision for some elastic expansion and contraction of the case. Farge, et. al.⁴ outlined the basic concepts for a model which would contain not only frictional effects, but also contributions from the bolt, firing pin, ejector, and extractor. The model, however, was not programmed. Jessick⁵ developed a proprietary failure-extraction model for analyzing ammunition reliability in the SPIW weapon. Potential rim shear and circumferential yielding failure calculations for the XM19 brass case were performed. An elastic-plastic model, utilizing some of the concepts of Farge⁴, was employed.

None of the above models were used to perform an extensive study of the 5.56 mm case in the conventional M16 weapon. In fact, little analytically obtained data concerning extraction in this system exists. This study fills this need. A computer code, HARRIS⁶, developed at Frankford Arsenal by J. Harris, was employed in the analysis of all the cartridge cases in this report. A brief documentation of the model, its assumptions, and improvements over previous analyses is presented in this report.

Two cartridge cases are considered: conventional cartridge brass, and X7475 (T6) aluminum. In order to properly assess the force of extraction, or extractability, of a spent case of each material, six potentially important geometric and materials parameters were varied. These are: (1) chamber-case clearances; (2) chamber pressures; (3) various yield strengths (or hardness levels) in the case; (4) friction; (5) chamber materials; and post yield behavior for brass.

²T. A. Read, et. al., "The Calculation of Yield Strengths in Steel Cases," FA-LC R-138, pp 1-27, February 1942.

³(No Author), "Mechanics of Cartridge Case Extraction for Aluminum and Other Metals," TR "68-3, Technik Inc., Jericho, NY, pp 1-74, July 1969.

⁴M. Farge and S. C. Pancholi, "The Development of a Rifle Extraction Force System Model," Singer - IJS Division, Silver Spring, MD, pp 1-53, February 1970.

⁵B. Jessick, et. al., "Case Extraction Study," A.A.I. Corp Report No. ER-5651, pp 1-59, March 1969.

⁶R. E. Donnard, "Memorandum for Record - Cartridge Case Extraction Model," pp 1-11, 9 May 1973.

THEORY

Basic Assumptions in the HARRIS Model

The rigorous procedures for establishing the state of stress and deformation of elastic-plastic flow in an explosively loaded metal, such as the cartridge case, lead to non-linear partial differential equations. These equations are quite complicated, and a numerical solution is mandatory. Thus, approximate methods or models are frequently used, particularly, when parametric design studies are to be performed.

The model used in the present study employs the following simplifying assumptions:

1. The case is a segmented, thin-walled, conical shell undergoing axisymmetric deformation. The effects of bending are neglected, and only in-plane or membrane stresses may act. Thus, each segment of the case is a membrane conical shell.
2. The inertia of the case (and chamber) are neglected.
3. Each segment of the case is unconnected from all others. No attempt to account for segment interaction is made.
4. Within each segment the stresses and deformation depend only on the radial coordinate, r . The strains and displacements are infinitesimal. The segments may not deform in the circumferential direction. The distributions of the stresses are constant, averaged through the thickness.
5. The flow in the case is linear elastic until yielding. The post-yield behavior is isothermal, elasto-plastic with linear strain hardening. The case material is at all times isotropic. An approximation to the Prandtl-Reuss plastic constitutive equation is used. The plastic strains are not incrementally used. The plastic strains are not incrementally cumulative, and the single loading step taken is so large as to be designated as a super-increment.
6. The yield strength may vary linearly with axial position within any segment, (a constant yield strength is a special case).
7. The chamber is always elastic.
8. All thermal effects are neglected.

9. The propellant pressure, P , is a constant along the axis of each segment and does not vary with time.

10. The force of extraction is assumed to be due only to the friction between case and chamber during extraction, less the residual or thrust propellant gas pressure force aiding extraction (Equation 6).

11. All external bending moments applied to the case by the extractor-ejector mechanism are neglected.

12. The bolt group and firing pin motions are neglected.

13. The peak interference pressure between case and chamber is the peak chamber pressure less the obturation pressure.

14. Unloading of case and chamber is linear.

A more specific and detailed documentation is given in Reference 6.

Equations in the HARRIS Model

From assumption 1 and Fluggee⁷, the equilibrium equations yield as the only non-vanishing stress components:

$$\sigma_{\theta} = Pr/t\cos\gamma \quad (1.a)$$

$$\sigma_z = Pr/2t\cos\alpha \quad (1.b)$$

$$\sigma_r = -P \quad (1.c)$$

for the conical segment shown in Figure 1. Here the subscripts θ , z , and r refer, respectively, to the hoop, axial and radial directions. P is the propellant pressure, t is the thickness, and α is the apex half angle.

⁶R. E. Donnard, "Memorandum for Record - Cartridge Case Extraction Model," pp 1-11, 9 May 1973.

⁷W. Fluggee, "Stresses in Shells," Springer-Verlag New York, Inc., NY, NY, pp 35-36, 1967.

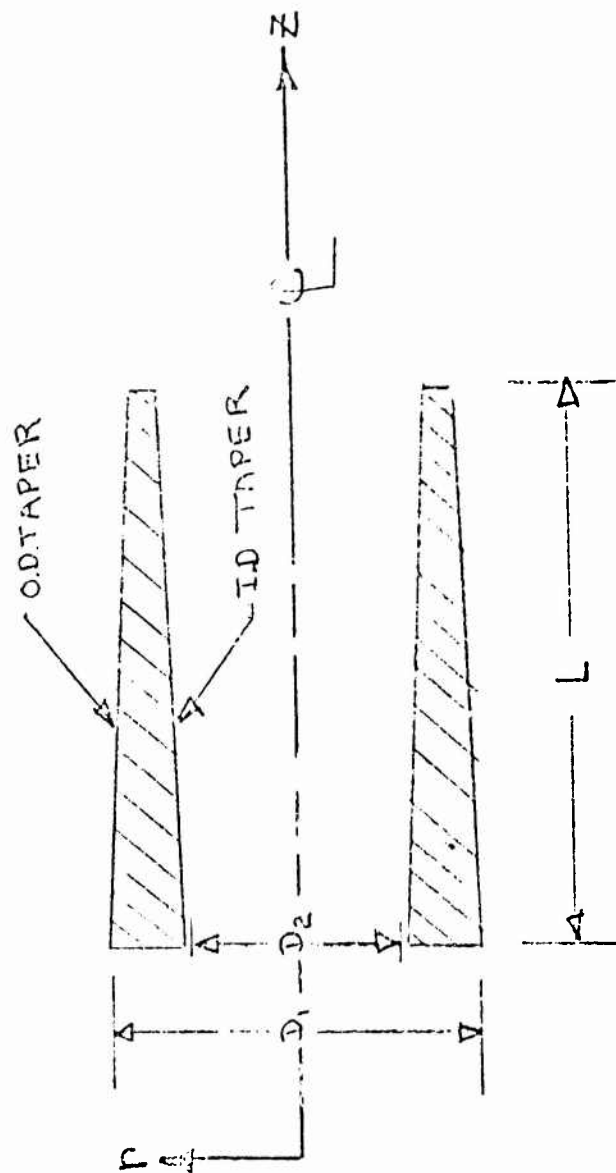


Figure 1. Geometry of a Typical Conical Segment Within the Cartridge Case

The constitutive relations follow from assumption 5 and Reference 8. The only non-zero components of total strain are thereby related to the stresses through:

$$\epsilon_r = \frac{1}{E} \left[\sigma_r - \nu (\sigma_\theta + \sigma_z) \right] + \beta \frac{\Delta \epsilon_p}{\sigma_e} \left[\sigma_r - 1/2 (\sigma_\theta + \sigma_z) \right] \quad (2.a)$$

$$\epsilon_\theta = \frac{1}{E} \left[\sigma_\theta - \nu (\sigma_r + \sigma_z) \right] + \beta \frac{\Delta \epsilon_p}{\sigma_e} \left[\sigma_\theta - 1/2 (\sigma_r + \sigma_z) \right] \quad (2.b)$$

$$\epsilon_z = \frac{1}{E} \left[\sigma_z - \nu (\sigma_\theta + \sigma_r) \right] + \beta \frac{\Delta \epsilon_p}{\sigma_e} \left[\sigma_z - 1/2 (\sigma_r + \sigma_\theta) \right] \quad (2.c)$$

where

$$\begin{aligned} \beta &= 0 \quad \text{if } \sigma_e \leq \sigma_Y \\ \beta &= 1 \quad \text{if } \sigma_e > \sigma_Y \end{aligned} \quad (3)$$

and σ_Y is the yield stress of the material.

Here σ_e is the equivalent plastic stress and $\Delta \epsilon_p$ is a super-increment of equivalent plastic strain, these two quantities are further connected through an equivalent stress - equivalent plastic strain curve. Thus for a given value of σ_e , the value of $\Delta \epsilon_p$ is established.

Equations 1 indicate that the problem of stress distribution is statically determined regardless of material behavior. With these known values of stress, the values of the total strain in Equations 2 are calculated. However, the displacements of the segment are not known until the kinematics are specified. The three non-zero displacement components are from assumption 4:

$$u = r \epsilon_\theta \quad (4.a)$$

$$\frac{du}{dr} = \epsilon_r \quad (4.b)$$

$$\frac{dw}{dz} = \epsilon_z \quad (4.c)$$

⁸A. Mendelson, Plasticity: Theory and Application, MacMillan Co., NY, NY, pg 103, 1968.

where u and w are, respectively, the displacement components in the radial and axial directions.

The displacement u is calculated from Equation 4.a. In the model Equations 4.b and 4.c are ignored. By not including Equation 4.b in the calculations, it can be shown that u will not, in general, be a continuous function of r . In fact, if u is eliminated in Equation 4 there results

$$r \frac{d\epsilon_{\theta}}{dr} + \epsilon_{\theta} = \epsilon_r \quad (5)$$

as a necessary condition for u to be continuous. The code, HARRIS, will not, in general, satisfy Equation 5. This has the physical interpretation that the cartridge case will not fit together after deformation. The error involved by the neglect of Equation 4.b in the present theory may be small compared to the numerous simplifications already made. This is substantiated, in part, by the fact that some of the resulting trends are qualitatively in agreement with practical experience.

We note that the system of Equations 1, 2, and 4.a are seven independent algebraic equations in seven unknowns: three stresses, three strains and one displacement. Thus, the system is determinate.

Calculation Procedure for Each Segment

1. The strains in the case are calculated from Equations 2, with the stresses given by Equations 1. Elastic flow or plastic flow is given by allowing β to be zero or one, respectively. u is calculated from equation 4.a in an iterative fashion until the case just contacts the chamber.

2. During loading of case and chamber, the interference pressure is calculated according to assumption 12; unloading according to assumption 13. There are two possibilities which may result after unloading:

- a. The case and chamber are not in contact.
- b. The case and chamber are still in contact with a resultant interference stress.

Extraction force calculations follow assumption 9. In case (a) the force necessary to extract is zero or negative depending on whether a rearward thrust from residual gas remains. In case (b) the force necessary to extract is positive, zero or negative according to whether the thrust is less than, equal to, or greater than the frictional force.

3. The total force of extraction, F , is calculated for the entire case from

$$F = \mu \sum_{n=1}^N \sigma_{r_n} A_n - P^* A^* \quad (6)$$

where μ is the coefficient of dynamic friction between case and chamber, A is the area of contact between segment and chamber, P^* is the residual pressure in the case at the time of extraction, and A^* is the net area inside the segment over which the unbalanced pressure acts. The force of extraction for the entire case is thus the sum of the forces of all segments less the thrust.

PARAMETRIC STUDY

This study consists of determining the effects on case extractability in the M16 weapon of six materials and geometric parameters. Both aluminum and brass cases are investigated. As has been previously indicated, the parameters varied are:

1. Initial clearance between case and chamber.
2. Peak propellant pressure within the case.
3. The hardness, or yield strength, levels found in the case.
4. The coefficient of static friction between the case and chamber wall.
5. Chamber elasticity.
6. Strain hardening behavior (of brass).

The cartridge case is divided into a number of large conical sections, called segments, as shown in Figure 1. It is necessary to specify the geometry and certain materials properties for each segment. Those parameters which were taken as "base" (in order to furnish a standard upon which comparison could be made) are shown in Table I and Table II for brass and aluminum, respectively. The meaning of several of the geometric factors are given in Figure 1. The variation in yield strength, Y , is assumed linear within a segment as shown in Figure 2. E is the elastic modulus, E' the plastic modulus, and ν is Poisson's ratio. P and μ are, respectively, the peak chamber pressure and coefficient of friction.

TABLE I.

Base Parameters for Brass Cartridge Case

	Segment Number				
	1	2	3	4	5
Case (psi)					
Y ₀	63.5 x 10 ³	63.5 x 10 ³	61.8 x 10 ³	35.3 x 10 ³	29 x 10 ³
Y _L	63.5 x 10 ³	63.5 x 10 ³	33 x 10 ³	29.3 x 10 ³	29 x 10 ³
E	14 x 10 ⁶	14 x 10 ⁶	14 x 10 ⁶	14 x 10 ⁶	14 x 10 ⁶
E'	17.3 x 10 ⁴	17.3 x 10 ⁴	17.3 x 10 ⁴	17.3 x 10 ⁴	17.3 x 10 ⁴
Chamber (psi)					
E	30 x 10 ⁶	30 x 10 ⁶	30 x 10 ⁶	30 x 10 ⁶	30 x 10 ⁶
Pressure (psi)					
	50 x 10 ³	50 x 10 ³	50 x 10 ³	50 x 10 ³	50 x 10 ³
Taper (in/in)					
Inside Diameter	-.069	-.0144	.0066	.9035	.0
Outside Diameter	.017	.017	.017	.856	.0
Barrel Radius (in)	.55	.55	.55	.55	.55
Clearance (in)	0	0	0	0	0
Diameter, D ₁ , (in)	.376	.370	.3634	.3545	.248
Diameter, D ₂ , (in)	.210	.333	.3388	.3354	.223
Length, L, (in)	.335	.390	.513	.124	.200
ν	.374	.374	.374	.374	.374
μ	.3	.3	.3	.3	.3

TABLE II.

Base Parameters for Aluminum Cartridge Case

	Segment Number			
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
Case (psi)				
Y ₀	70 x 10 ³	65 x 10 ³	24 x 10 ³	24 x 10 ³
Y _L	70 x 10 ³	22.7 x 10 ³	24 x 10 ³	24 x 10 ³
E	10.5 x 10 ⁶	10.5 x 10 ⁶	10.5 x 10 ⁶	10.5 x 10 ⁶
E'	26.5 x 10 ⁴	26.5 x 10 ⁴	26.5 x 10 ⁴	26.5 x 10 ⁴
Chamber (psi)				
E	30 x 10 ⁶	30 x 10 ⁶	30 x 10 ⁶	30 x 10 ⁶
Pressure (psi)				
	50 x 10 ³	50 x 10 ³	50 x 10 ³	50 x 10 ³
Taper (in/in)				
Inside Diameter	-.0667	-.0052	.878	.00
Outside Diameter	.017	.017	.878	.00
Barrel Radius (in)	.55	.55	.55	.55
Clearance (in)	0	0	0	0
Diameter, D ₁ , (in)	.376	.370	.355	.247
Diameter, D ₂ , (in)	.304	.326	.331	.223
Length, L, (in)	.335	.903	.123	.200
ν	.25	.25	.25	.25
μ	.3	.3	.3	.3

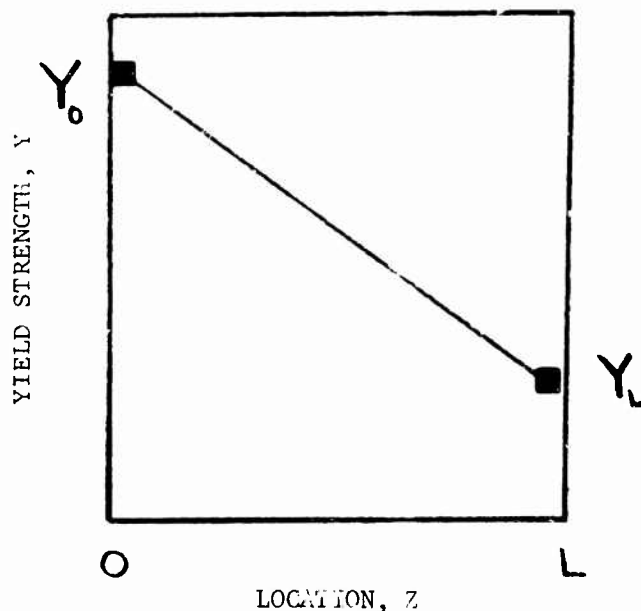


Figure 2. Linear Variation of Yield Strength with Location in the Segment of Figure 1

The actual division of the cases into segments is shown in Figures 3 and 4. This division is based upon the change in the geometry along the case, and the change in the yield strength within the case. Standard case drawings F.A. 10524200 and F.A. 10542721 were used to obtain the dimensions used. Minimum dimensions and hardness levels were used in this study in order to provide a conservative estimate for case performance.

The yield strength gradients along the cartridge cases used in this study are shown in Figures 5 and 6. Figures 5 and 6 were prepared from hardness measurements (for aluminum) and specifications (for brass) along the case. For the cartridge brass the specified hardness gradient as a function of position along the case was obtained from drawing FA 10524200 and correlated⁹ with yield strength as shown in Figure 7. The result is Figure 5. For the 7475-TMT aluminum case hardness gradients were measured¹⁰ using a standard Vickers procedure

⁹ W. Shebest, Personal Communication

¹⁰ M. Rosenbaum, Personal Communication

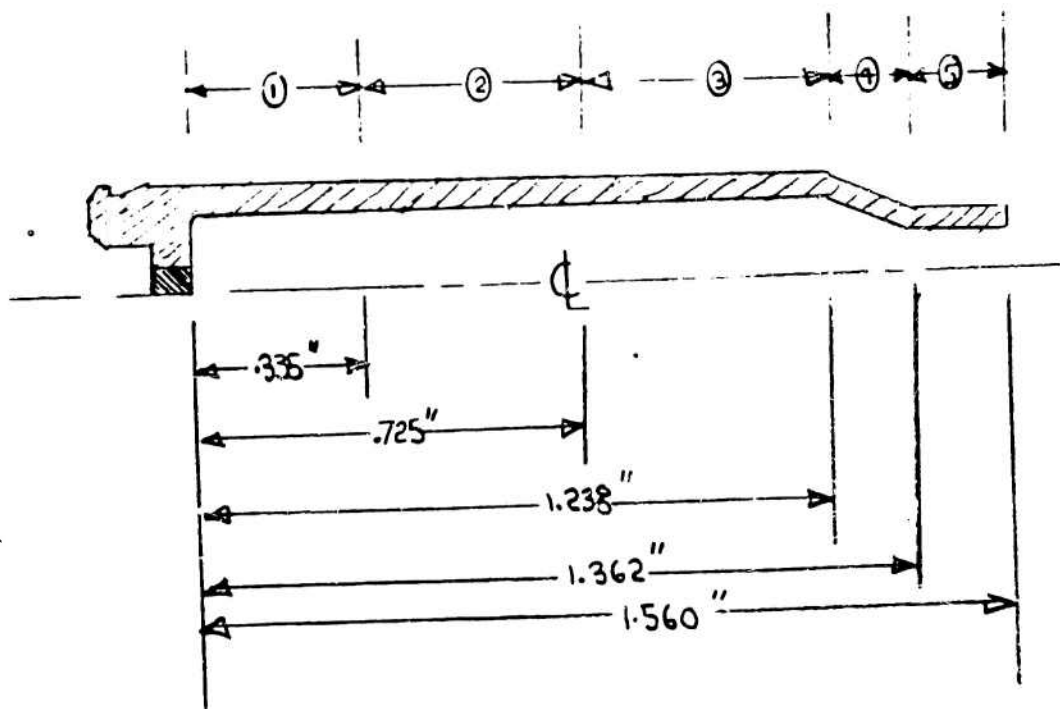


Figure 3. Division Scheme Used for the Brass Case. (Numbers Correspond to Segments in Table I.)

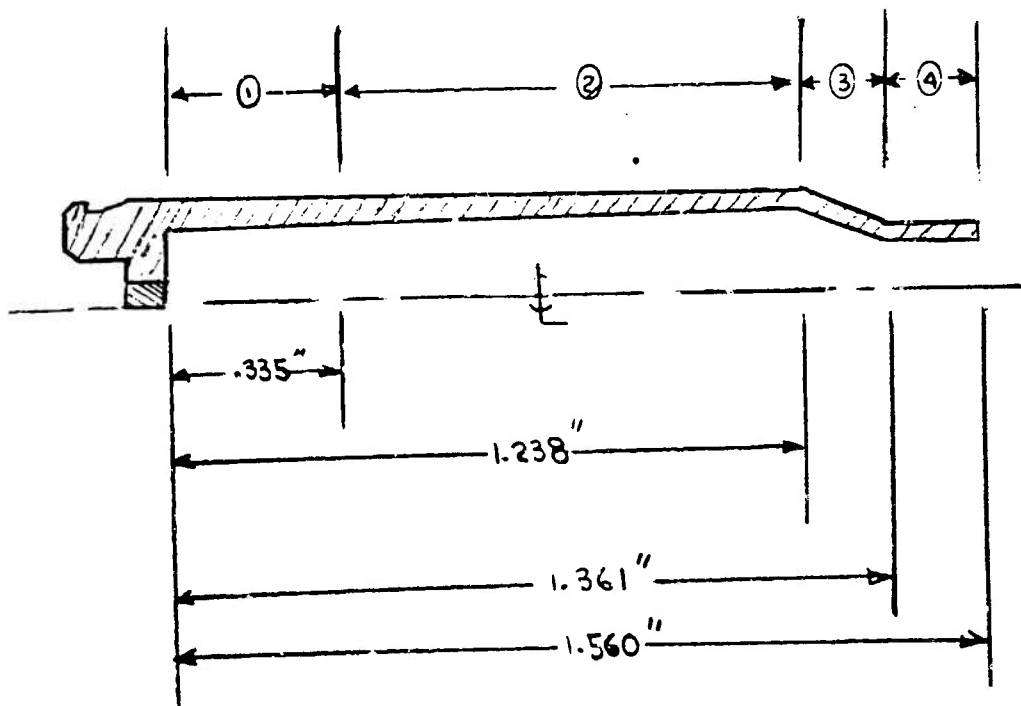


Figure 4. Division Scheme Used for the Aluminum Case. (Numbers Correspond to Segments in Table II).

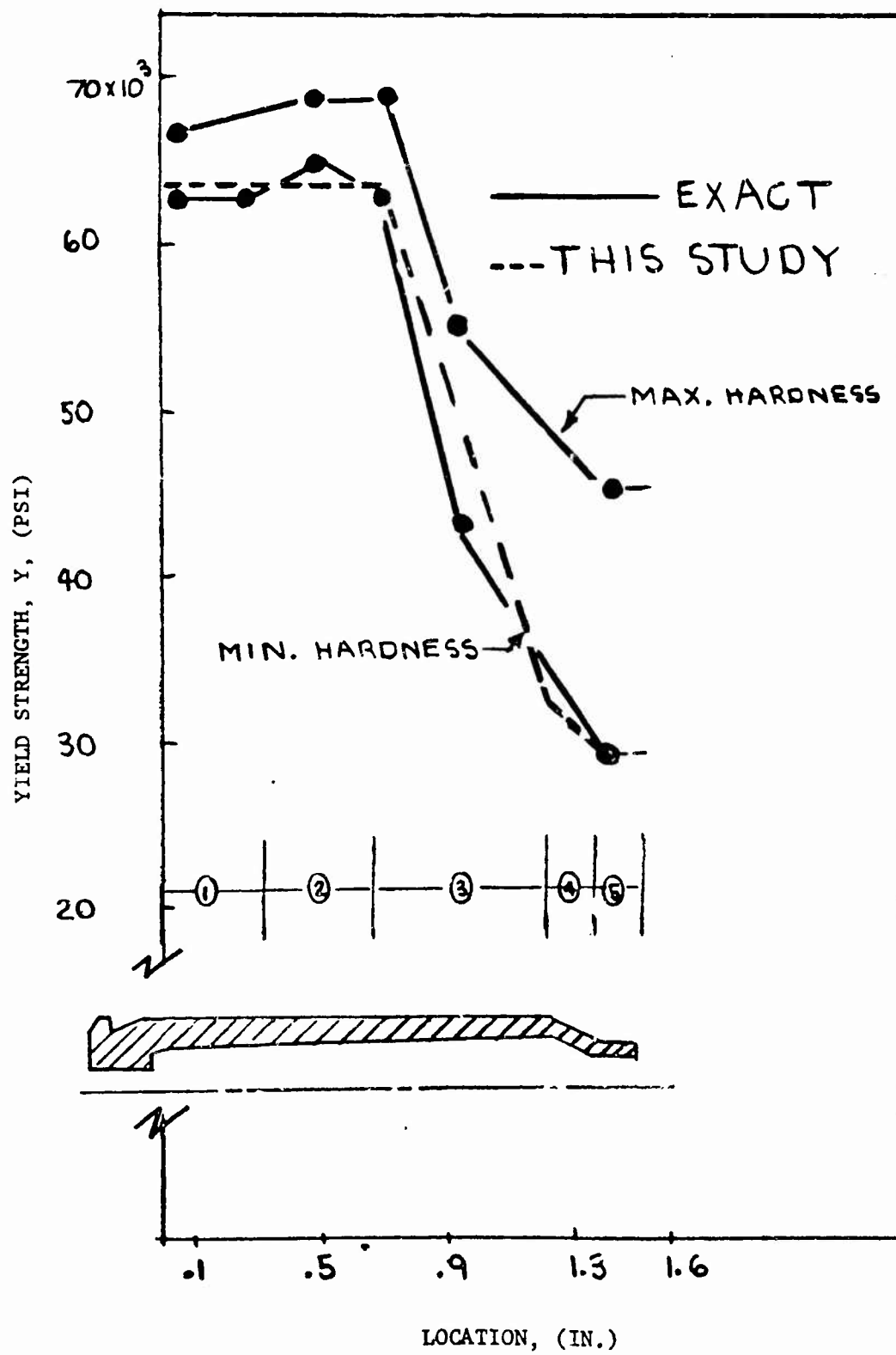


Figure 5. Yield Strength Variation Within the Brass Case

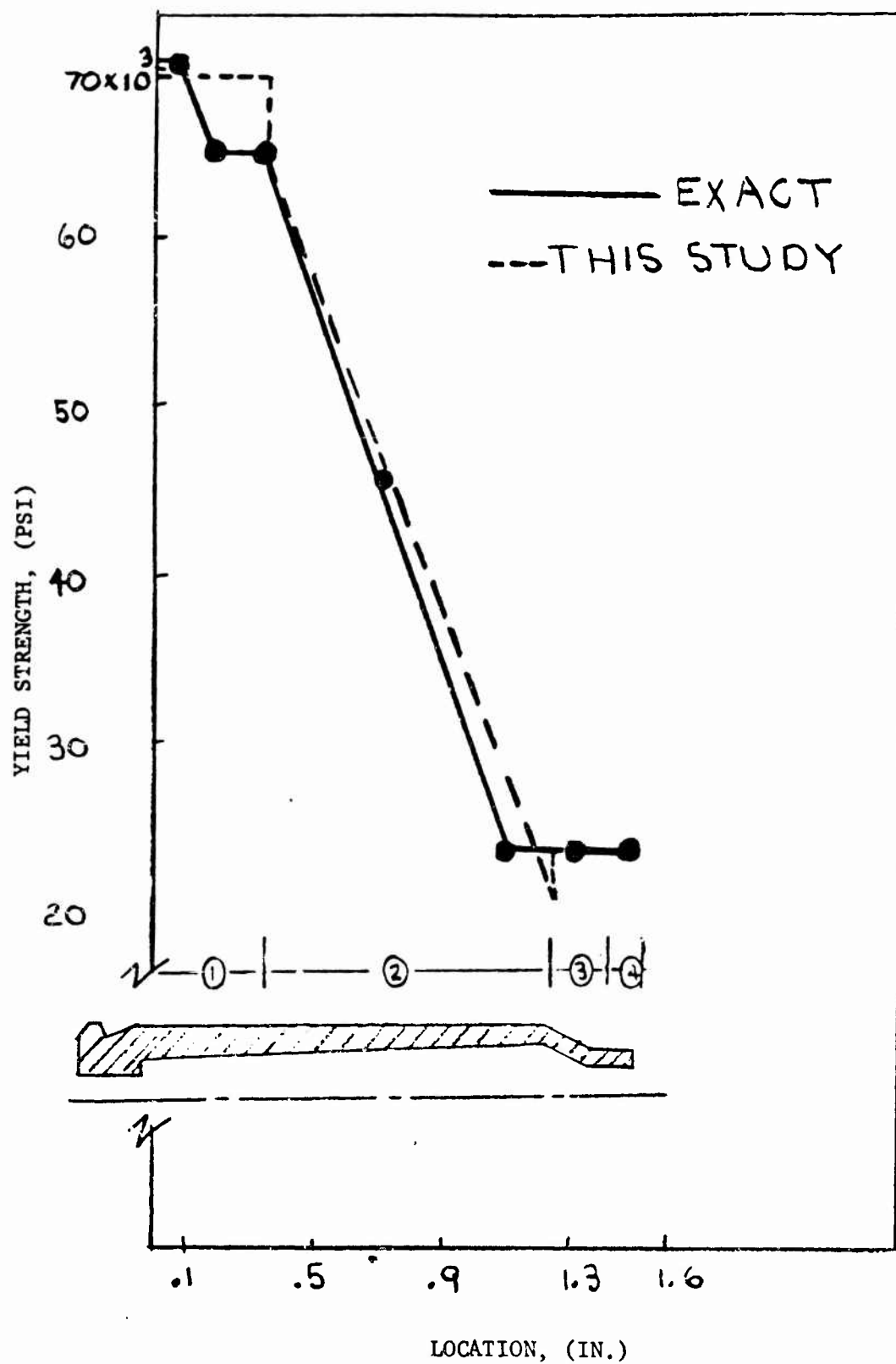


Figure 6. Yield Strength Variation Within the Aluminum Case

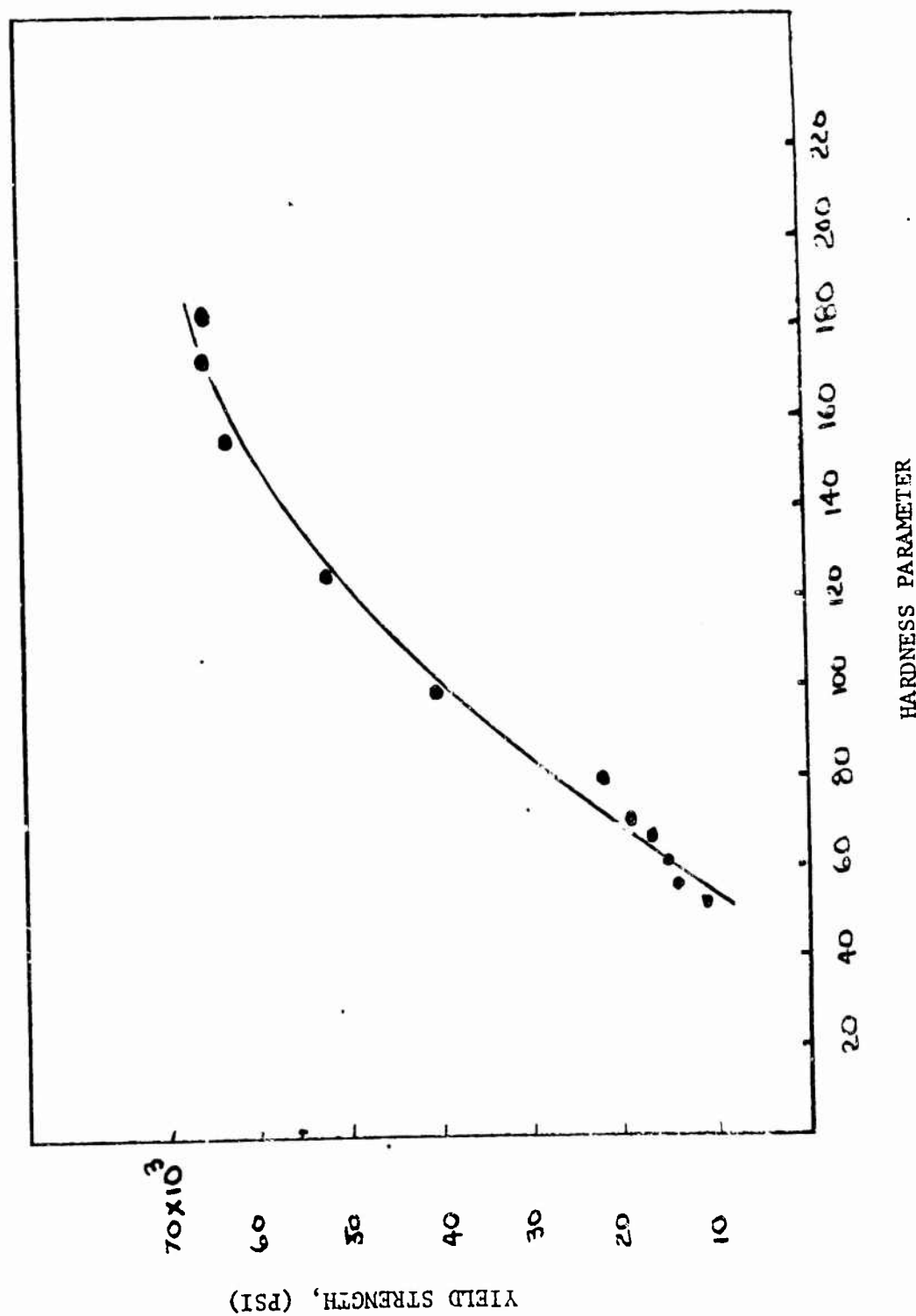


Figure 7. Estimated Variation of Yield Strength With Vickers Hardness Parameter (DPH) for Brass

on experimental cases. These hardnesses were then correlated¹¹ with initial yield strength through tensile tests on flat sheets pre-hardened to the necessary hardness. This correlation is shown in Figure 8. The final correlated yield distribution is given in Figure 6.

Table III presents the range of values for each of the six studies performed. Three values for each parameter in studies 1, 2, 4, 5, and 6, including the base value, were used. Except for the quantity being varied, all other parameters are as shown in Tables I and II. The yield strength in study 3 is held constant along the entire length. Note, however, that the yield strength is not constant in studies 1, 2, 4, 5, and 6.

RESULTS AND DISCUSSION

The results of the parametric study are shown in Figures 9 through 19. In each of these figures, the calculated force of extraction is plotted against the appropriate variable of Table III. Each force curve is plotted at three assumed values of residual pressure in the case at the instant of extraction. It is assumed that values between 0 and 2×10^3 psi bracket normal M16 functioning.

It is immediately obvious from Figures 9 through 19 that many of the extraction forces are zero or negative. These correspond, respectively, to the situations in which the residual pressure force or blowback force is just equal to or greater than the retarding friction force (viz, Equation 6). In practice, a zero or negative force is not encountered since the bolt group, extractor-ejector mechanism and case inertia influence the motion of the case. These factors, as mentioned previously, are neglected here. These facts, however, do not at all prevent using the results for a qualitative comparison of the various parameters influencing extraction.

The general qualitative trends are summarized briefly in Table IV for both brass and aluminum. These trends apply for the operating range of 0 to 2×10^3 psi back pressure. The only exception is the aluminum case at 2×10^3 psi. Table V is a material comparison of the relative ease of extraction for several of the parameters in the study. This table was prepared from Figures 9 through 19. As can be seen, the 7475-TMT case is, generally, superior to conventional cartridge brass with respect to ease of extraction. This is particularly true when the back pressure in the case at the instant of extraction does not exceed 1×10^3 psi. It should be noted from Figures 9 through 19 that this superiority is slight in some cases and is quite sensitive to the input parameters.

¹¹ A. Zalcmann, Personal Communication

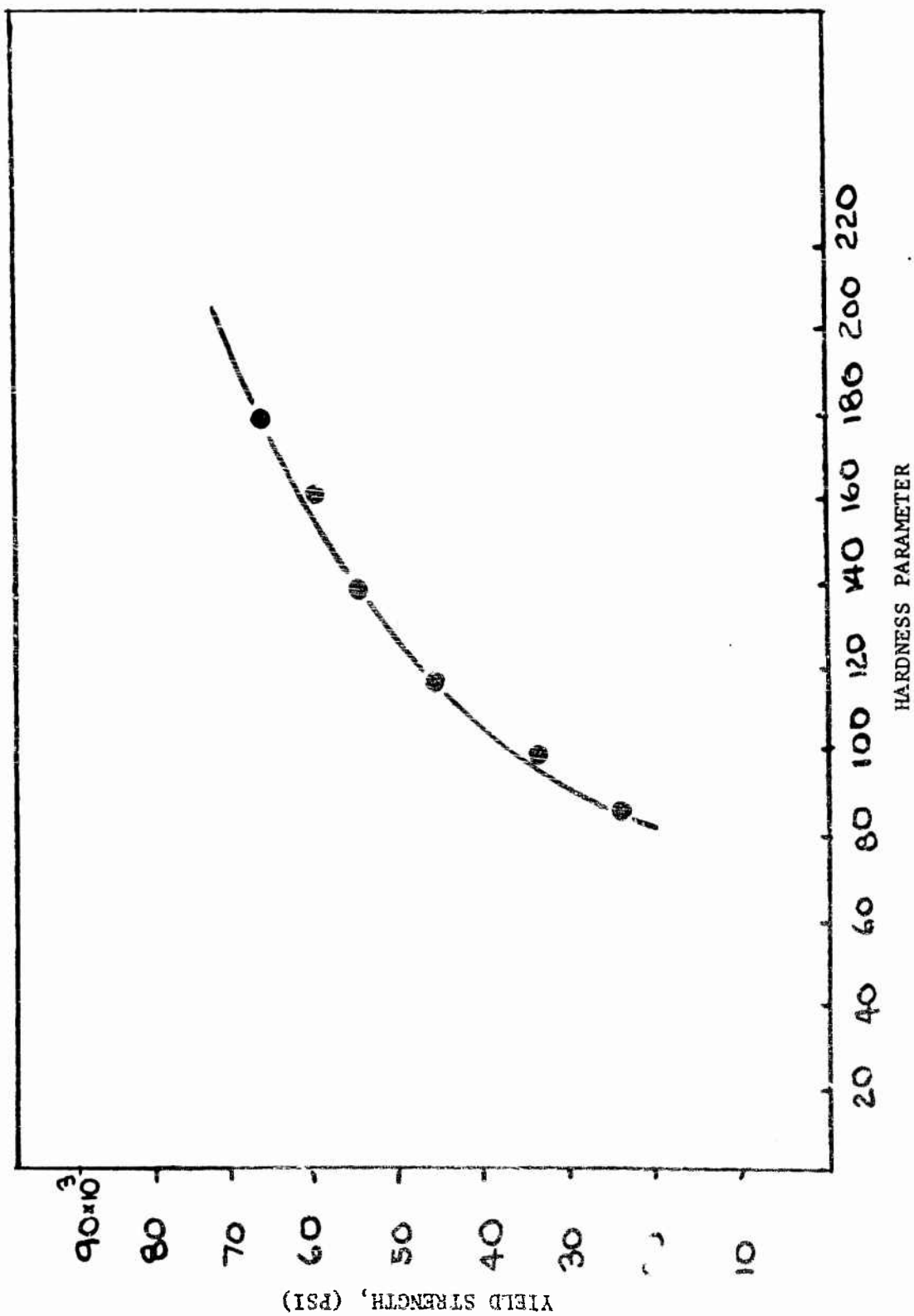


Figure 8. Estimated Variation of Yield Strength with Vickers Hardness Parameter (D.P.H) for 7475-T6 Aluminum

TABLE III.

Range of Parameters

Study No.	Parameter Under Study	Values			
		Brass		Aluminum	
1	Clearance (in)	0 ^a	2.5×10^{-3}	5×10^{-3}	0×10^{-3} 2.5×10^{-3} 5×10^{-3}
2	Peak Pressure (psi)	40×10^3	50×10^3	60×10^3	40×10^3 50×10^3 60×10^3
3	Yield Strength (psi)	29×10^3 ^b	50×10^3 ^b	63×10^3 ^b	24×10^3 ^b 50×10^3 ^b 70×10^3 ^b
4	Coefficient of Friction	0.2	0.3 ^a	0.4	0.2 0.3^a 0.4
5	Chamber Modulus (psi)	20×10^3	30×10^3 ^a	40×10^3	20×10^3 ^a 30×10^3 ^a 40×10^3
6	Case Plastic Modulus (psi)	1.73×10^4 ^a	5.0×10^4	7.5×10^4	--- --- ---

^a Base conditions from Tables I and II.^b Treated as a constant for the entire case.

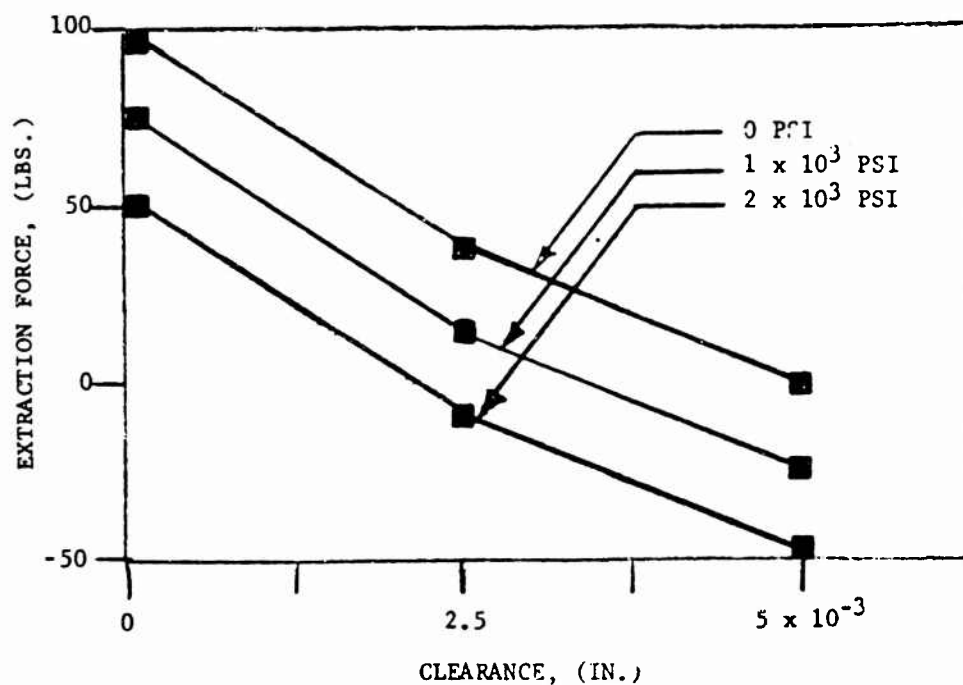


Figure 9. Extraction Force vs Clearance at Three Residual Pressures (Brass)

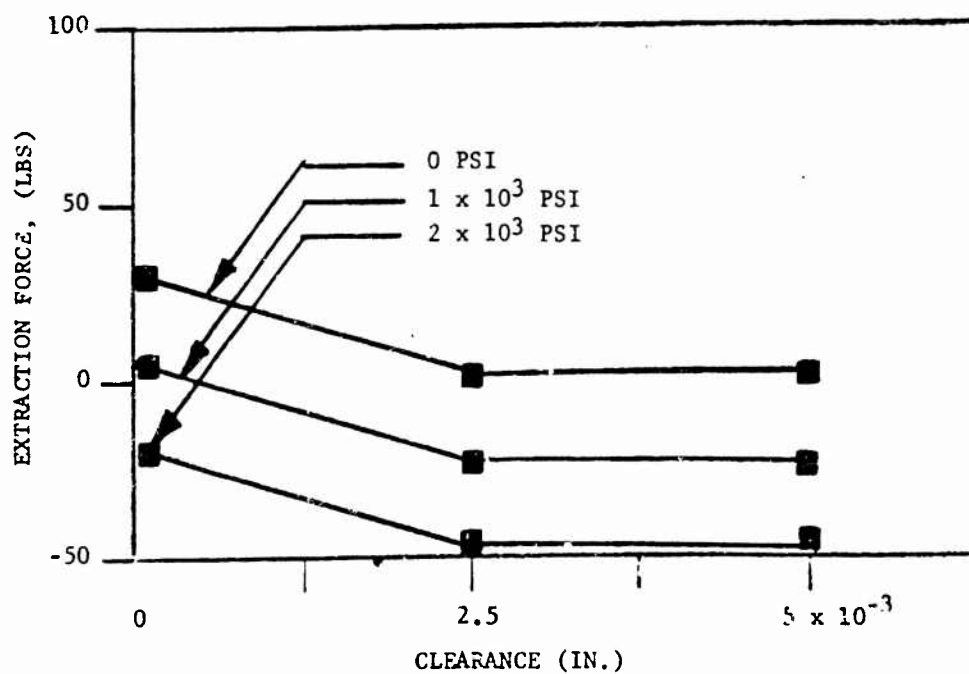


Figure 10. Extraction Force vs Clearance at Three Residual Pressures (Aluminum)

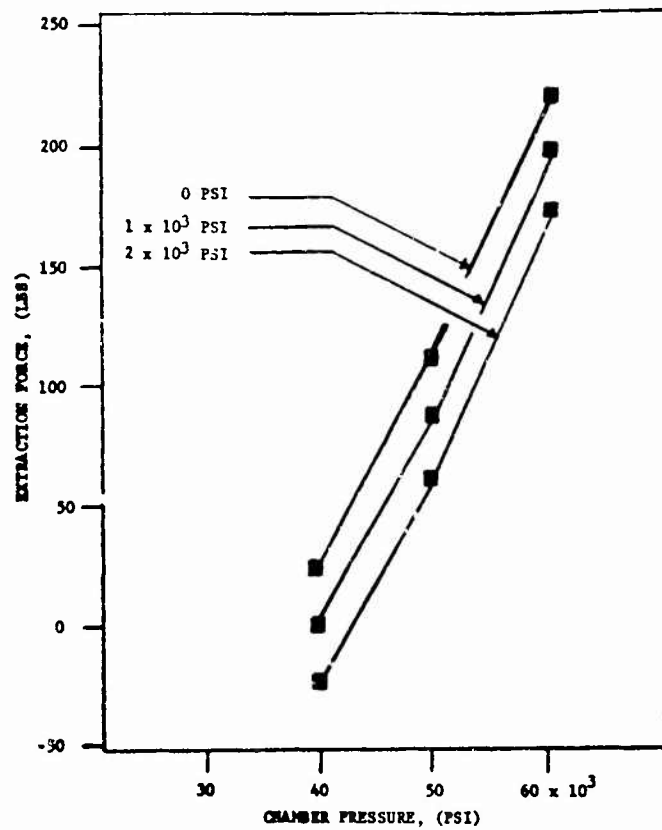


Figure 11. Extraction Force vs Peak Chamber Pressure at Three Residual Pressures (Brass)

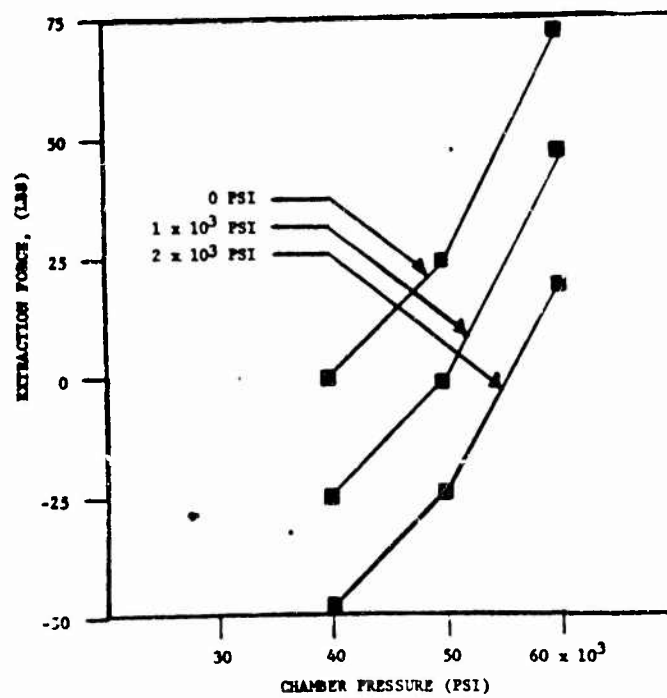


Figure 12. Extraction Force vs Peak Chamber Pressure at Three Residual Pressures (Aluminum)

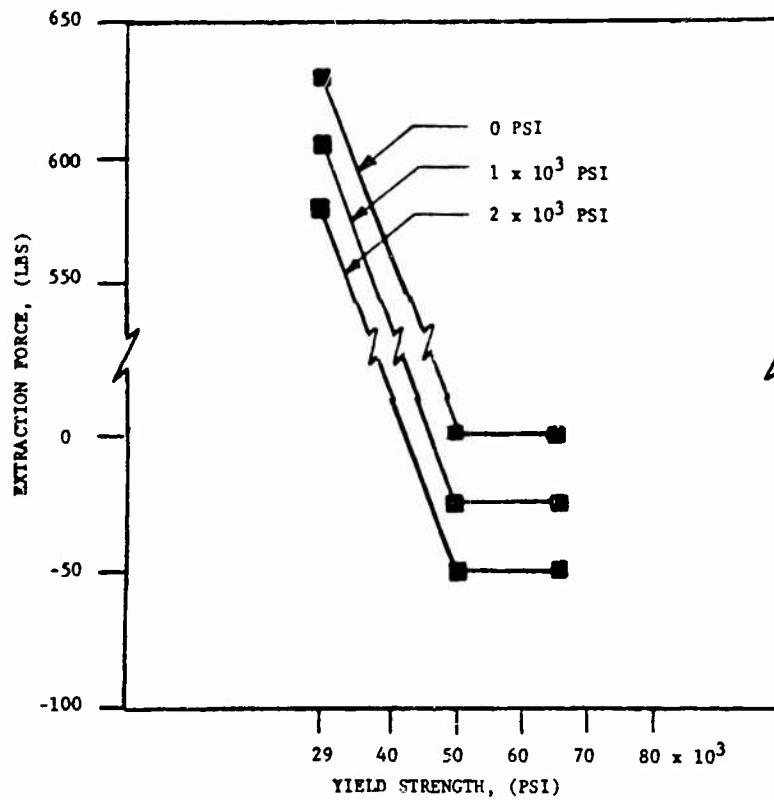


Figure 13. Extraction Force vs Yield Strength at Three Residual Pressures (Brass)

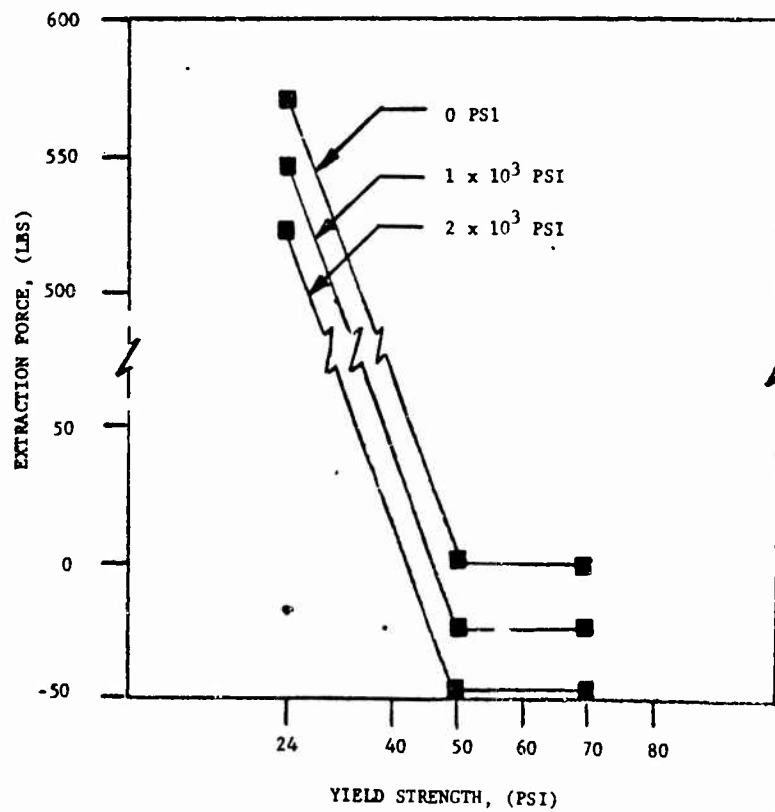


Figure 14. Extraction Force vs Yield Strength at Three Residual Pressures (Aluminum)

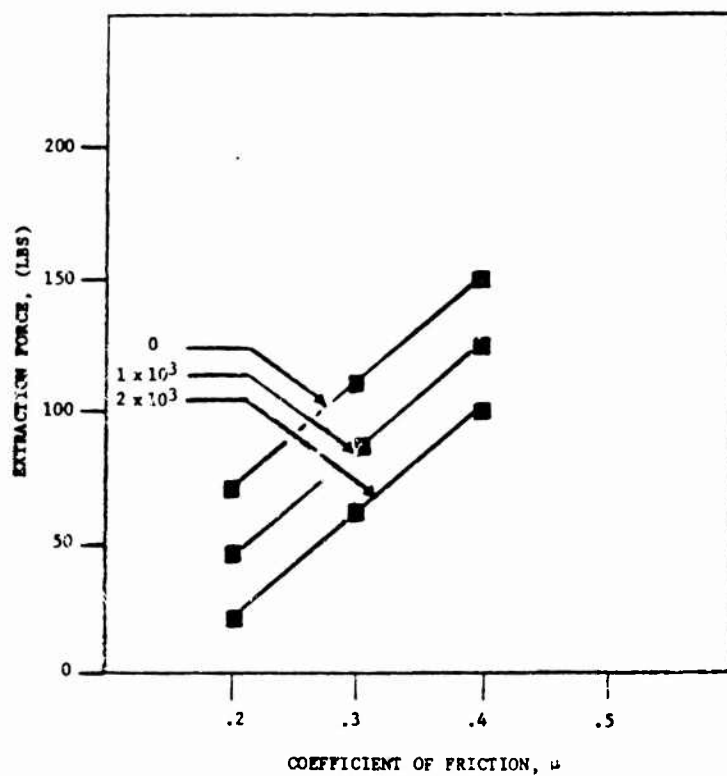


Figure 15. Extraction Force vs Coefficient of Friction at Three Residual Pressures

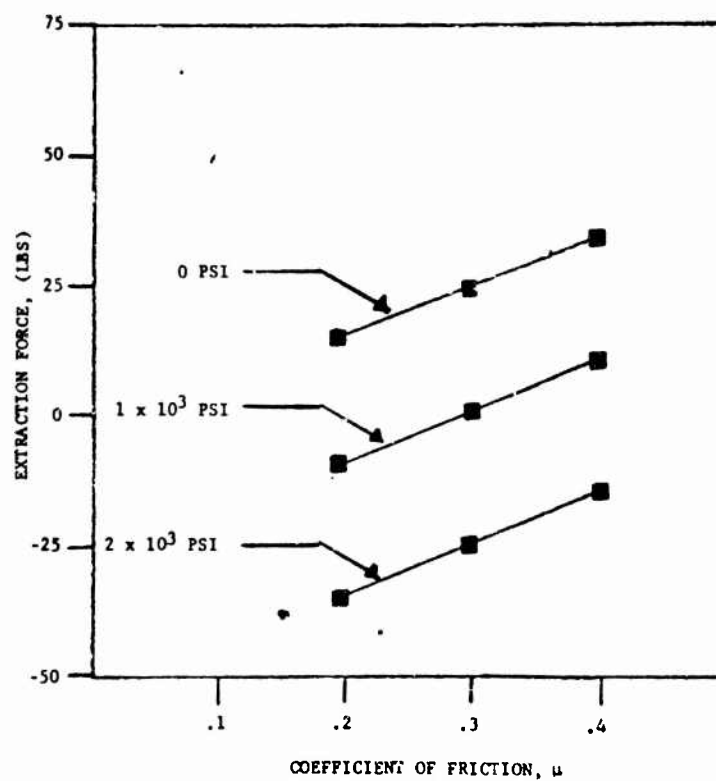


Figure 16. Extraction Force vs Coefficient of Friction at Three Residual Pressures (Aluminum)

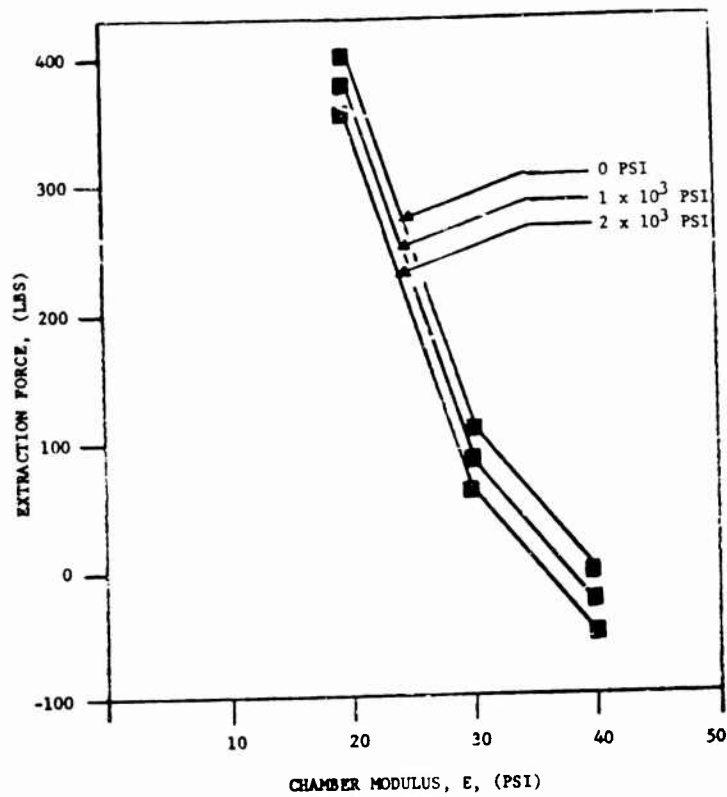


Figure 17. Extraction Force vs Chamber Modulus at Three Residual Pressures (Brass)

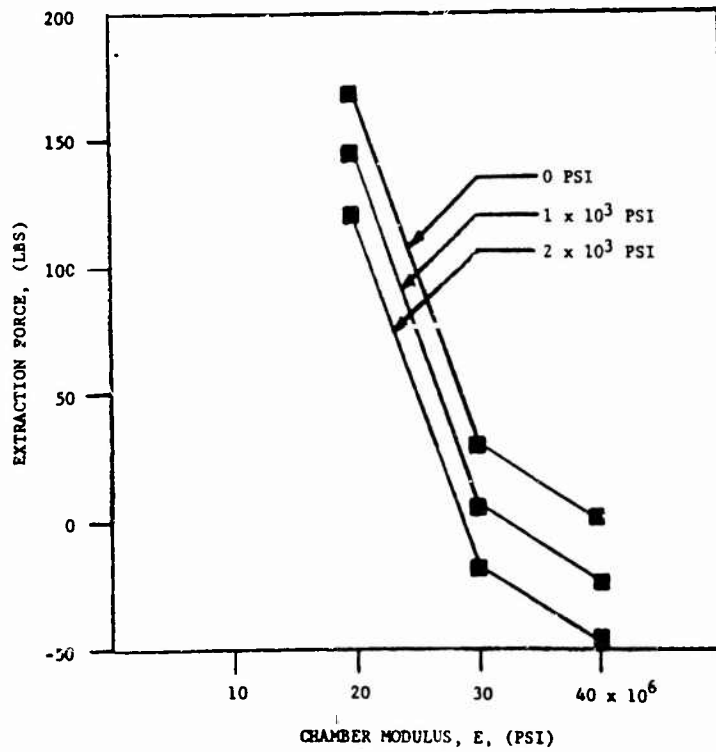


Figure 18. Extraction Force vs Chamber Modulus at Three Residual Pressures (Aluminum)

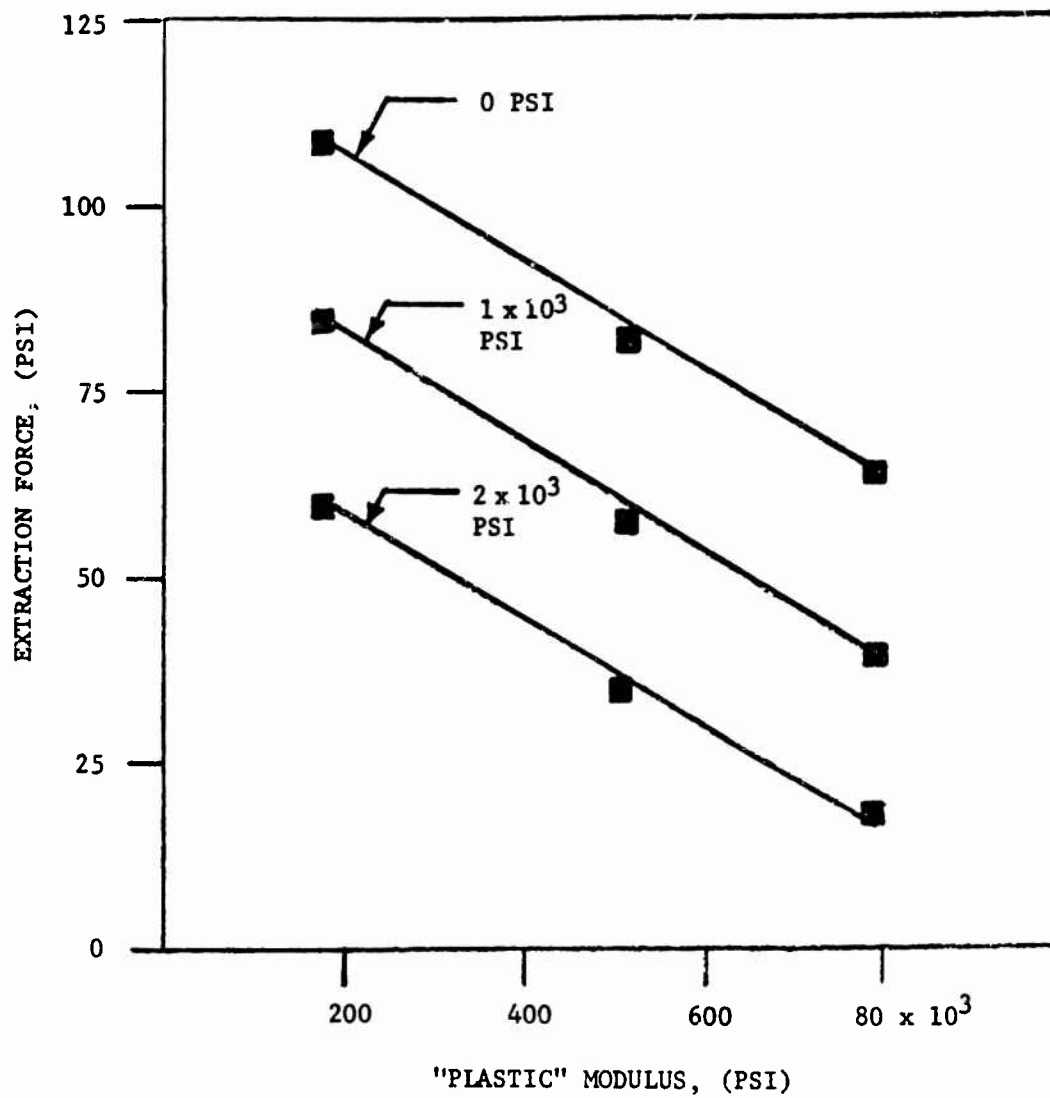


Figure 19. Force of Extraction vs Plastic Modulus at Three Residual Pressures

TABLE IV.

Qualitative Trends in Extraction Force for
Brass and Aluminum 5.56 mm Cases in the M16

<u>Study No.</u>	<u>Increasing Parameter</u>	<u>Force of Extraction</u>
1	Initial Clearance	Decreases
2	Peak Chamber Pressure	Increases
3	Yield Strength or Hardness in the Case	Decreases
4	Friction Between Case and Chamber	Increases
5	Chamber Modulus	Decreases
6	Slope of the Post-Yield* Stress-Strain Curve	Decreases

* Brass Only

TABLE V.

Comparison of Predicted Ease of Extraction
Between Brass and Aluminum 5.56 mm Cases

<u>Increasing Parameter</u>	<u>Superior Material</u>		
<u>Back Pressure</u>	<u>0</u>	<u>1</u>	<u>2 x 10³ psi</u>
Clearance	A1	A1	A1 ^a
Propellant Pressure	A1	A1	A1
Coefficient of Friction	A1	A1	A1
Chamber Modulus	A1	A1	A1 ^b

^a Except at .005 in clearance when they are equal

^b Except at 40 x 10⁶ psi when they are equal

In a similar study⁵ with the SPIW weapon, a number of factors controlling the force of extraction were identified and examined. In that study it was found that the coefficient of friction and residual gas pressure were the most important factors with a somewhat lesser, but still important role played by: case thickness, hardness, barrel thickness, and peak chamber pressure. The results of the present study identify some of the same factors as important but, moreover, indicate several others. These are: clearance, chamber modulus and post-yield behavior.

It is important to note that there are several factors not included in this model which warrant additional investigation or modification. Since the cartridge case is heated by propellant burning there may be a significant, though transient, increase in temperature. Depending upon the distribution and duration of this temperature rise in the case wall several structural changes may occur. These are:

1. The case may become entirely plastic at a significantly lower propellant pressure than reported here. Thus the amount of subsequent plastic and elastic strain is increased.
2. The yield strength of the case may be degraded if the temperature is sufficiently high¹², thus affecting the residual stress pattern and, hence, the extraction force.
3. There is some evidence¹³ from experiment that the inertia force of the case during extraction is not negligible compared to the residual gas pressure force in the weapon.
4. The effects of blowback may be more accurately calculated by replacing the $P^* A^*$ thrust term in Equation 6 by an "equivalent" axial force correctly distributed over each tapered segment. An example of the correct procedure for performing this modification is given in Bland.¹⁴

⁵ B. Jessick, et. al., "Case Extraction Study," A.A.I. Corp. Report No. ER-5651, pp 1-59, March 1969.

¹² B. Boley and J. Weiner, Theory of Thermal Stress, John Wiley and Sons, Inc., NY, NY, pp 566-569, 1960.

¹³ M. Horchler, Private Communication

¹⁴ D. R. Bland, Journal of the Mechanics and Physics of Solids, Vol 4, pg 211, 1956.

CONCLUSION

Based on the results of this study and subject to the restrictions mentioned in the Discussion, it is concluded that the 7475-TMT case is superior in ease of extraction to conventional cartridge brass.

RECOMMENDATIONS

Based upon the above Discussion there are several specific recommendations necessary for increased accuracy and additional refinement to the model. These are:

1. Incorporation of transient thermal effects.
2. Consideration of case inertia at extraction (Equation 6).
3. Consideration of the compatibility of strains (Equation 5).
4. Experimental verification of the trends of Tables IV and V.
5. Consideration of the effect on extraction force of tolerances on case dimensions.
6. Re-evaluation of the methods used to account for blowback.
7. Correction for effects of chamber taper on normal extraction.

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